ADAPTIVE BEAMFORMING OF STEERABLE ARRAY MONOPOLE ANTENNA FOR WLAN APPLICATION

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ABSTRACT

The modern communication systems are using smart portable devices that operate on WLAN frequency of 2.45 GHz. One of the serious limitations of handled devices is difficult to achieve a direct connection between the transmitter and receiver. Therefore, a smart steerable patter array antenna is highly recommended for new generation communication. Using low-cost steerable passive monopole array antenna can achieve a beam steering and high gain. Loading an additional reactance to the passive elements of the array are changed the mutual coupling between the arrays, which leads to steering the pattern to the desired direction. However, this needs fast process accurate optimised parameters. In this study, four passives one active monopole array antenna is proposed and simulated by using CST Microwave Studio software. The adaptive beamforming is proposed by using downhill simplex algorithm. The results show that the optimum reactance values are suggested after 0.074 second with 94 iterations to achieve a direction of arrival of 180° and 0°. The simulated radiation is successfully steered to the direction of 180 ° by adding the suggested reactance into the passive elements. Furthermore, the antenna gain is improved by 1.3 dBi that achieved a value of 5.3 dBi.The envelope-cross-correlation (ECC) shows magnitudes less than 0.5 among the elements. This algorithm successfully is provided with the optimum reactance values. The proposed approach can be considered a fast and significant candidate for new generation of smart communication WLAN applications.

ABSTRAK

Sistem komunikasi moden menggunakan peranti mudah alih pintar yang beroperasi pada WLAN frekuensi 2.45 GHz.Salah satu keterbatasan yang serius dalam pengendalian peranti mudah alih adalah sukar untuk mendapt sambungan terus antara permancar dan penerima. Oleh itu,antenna tatasunan boleh arah yang pintar dicadangkan untuk komunikasi generasi baru. Gandaan tinggi dan paten boleh dapat dicapai dengan menggunakan antenna pasif tatasunan boleh arah.Dengan menambah reaktansi pada elemen pasif ,is mengubah arah paten pada isyarat yang dikehendaki .Walaubagaimanapun,ini memerlukan pross yang sangat pantas untuk proses pengoptimuman parameter.Dalam kajian ini, empat elemen pasif dan satu elemen aktif monople antenna tatasunan dicadangkan dan disimulasi menggunakan perisian CST Microwave Studio. Algoritma Simplex Method dicadangkan untuk beamforming. Keputusan menunjukkan nilai reaktansi yang optimum diperolehi selepas 94 lelaran untuk arah ketibaan 180° dan 0°. Radiasi simulasi Berjaya diarahkan ke 180° dengan menambah nilai reaktansi yang dicadangkan pada elemen pasif .Tambahan pula ,nilai gandaan meningkat sebanyak 1.3dBi untuk mendapat nilai gandaan 5.3dBi.ECC yang diperolehi kurang dari 0.5 antara elemen . Algoritma ini Berjaya memberi nilai rektansi yang optimum. Pendekatan yang dicadangkan boleh dianggap sebagai calon yang sesuai untuk generasi baru aplikasi pintar WLAN.

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WLAN	Wireless local area network
SINR	Signal to Interference plus Noise Ratio
ESPAR	Electronically steerable passive array radiator
CST	Computer simulation technology
Z	Impedances
CCC	Cross-correlation coefficient
GA	Genetic algorithm
FDTD	Finite-Difference Time-Domain

CHAPTER 1

INTRODUCTION

1.1. Research Background

Wireless local area network (WLAN) access has become a norm in our up to date society, but only twenty years ago, some standards did not survive. In 1997, the original IEEE 802.11 WLAN standard was demonstrated [1]. However the data rate was strength less and it was not widely modified, until the operation of the succeeding 802.11b standard. Both laptop computers and mobile are widely seen and increase popularity in the beginning of the twenty first century. Connecting a laptop to an Ethernet, wire connector to get access to the internet serves is considered a convenient to customers. The IEEE 802.11 standard has developed to enable free access to the Internet remotely. In 2003, IEEE 802.11g standard with 5 times transfer's data faster than IEEE 802.11b introduced for high data rate. After that, up to a 150 Mb/s data rate is achieved by developed the IEEE 802.11n standard in 2009.

Global communication systems play a significant role in commercial companies and handheld devices on WLAN band. A monopole array antenna is one of the most capable types for high gain and low-cost antenna design. Recently, controlling the propagating signal direction of both the transmitted and resaved antenna is considered as one of the interesting subject for modern communication system. Usually, the designers have tried to developing products with low cost and high performance. Existing communications systems have some serious limitations for global communications. The direct link can be realised between the transmitter and the receiver for fixed antenna location only due to its practical applications in diverse areas; a significant amount of research has been devoted to investigate the problem.

Existing portable devices communications systems have some severe limitations for global communications. Due to its practical applications in diverse areas, a significant amount of research has been devoted to investigating this problem missing links to the future flexible wireless communication systems. The mechanical moving the reflector is used to steer the antenna beam done by [2]. While the mechanical steerable antennas are considered inexpensive, recent antennas that utilised the electro-mechanical actuator are usually bulky and prone to mechanical failure. However, a steerable passive monopole array antenna is related to the number of active elements. The antenna beam steering can also be done by changing the impedance of one or several monopole elements. This study has focused on the design and development of a low-cost steerable adaptive monopole array antenna. This newly proposed tuneable array antenna design is anticipated to be easy to control the radiation directivity of the proposed design.

1.2. Problem Statement

Several applications are developed their performance by using smart antennas [3]-[4]. The received antenna is presented by electronically steerable passive array radiator (ESPAR) antenna [5], which is widely used based on low manufacturing cost for beamforming applications, while the analog-to-digital (ADC) is required. Currently, many researches on smart antenna have been conducted. Array antennas that can be control the pattern and steer into the desired element is called smart antennas. A conventional ESPAR antenna is designed with single active element, which is connected to the ADC and a several passive elements adjacent it in a round. Every single passive antenna is connected into a series varactor diode, which are variable capacitance change the magnitude and phase of the current in the antennas, due to the controlled voltage that applied to the varactor. The passive antennas controlled the shape of array radiation pattern, therefore the nulls in the resulting pattern.

There are several types of adaptive array antennas; switched-beam array tenable voltage passive array and adaptive beamforming antenna. It should be pointed out that the control voltages are reversely loaded at the diode to realize reactance. Using monopole elements simplifies the antenna's configuration and the reactance circuit. Radiation-pattern effects caused by RF currents flowing on dc lines and the feed cable are also reduced. Moreover, another type of steering pattern is presented by switched beam array antennas, which can change the direction of the peak power only. Simultaneously, the radiation can be controlled in all directions by using adaptive beamforming. According to [6], the adaptive antenna is the best choice to solve this chilling. An array antenna with reactive load is steer the radiation pattern with a single receiver. The pattern can be changed by altering the reactive loads for reactively antenna array. By connection variable impedance with the passive monopole antennas elements, the highest gain direction of the passive elements can interfere with the radiation pattern of the active antenna element. As a result, the overall array antenna gain direction will steer to a specific direction. Many researchers have been utlised adaptive beamforming of array antenna. However, this study is introduced a steerable monopole array antenna with 180° controlling the radiation pattering. Moreover, the peak directivity of an adaptive array antenna using monopole elements improved by constructing an ESPAR antenna with a finite ground plane below monopole elements [7].

1.3. Objectives

The objectives of this project are:

I. To propose a monopole array antenna for WLAN applications.
II. To investigate the performance of the proposed steerable antenna in term of (the gain, the radiation pattern, the return loss, and Signal to Interference plus Noise Ratio (SINR)).

1.4. Research Scope

This study has a scope can be summarised as:

I. Design and modelled the proposed antenna of 2.4 GHz by using computer simulation technology (CST) Microwave Studio software.
II. Design the proposed array antenna by using (FR-4) substrate.
III. Develop an adaptive beamforming algorithm by using MATLAB software.

1.5 Project Outline

This project contained five chapters, which are summarised as follows:

Chapter one illustrates the background about the proposed study and the problem statement that can be solved. Also, the objectives of this study and the research scope are included to present this study shortly.

Chapter two presents the literature of monopole antenna fundamental calculation. Also the steerable array techniques are summarised. Different articles are discussed in this chapter.

Chapter three shows the parameters of the proposed monopole antenna. The simulation setup of the proposed array is introduced .also the utilised algorithm optimisation process is demonstrated in this chapter.

Chapter four shows the achieved results of the proposed array monopole antenna. After that the optimisation results of the additional passive reactance is demonstrated. Finally, the steerable pattern results are compared of three directions by connecting the optimised impedance.

Chapter five summarised the project performance and results. Also, it shows the advantages of the proposed algorithm. Finally several points are demonstrated future work of this study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the monopole antenna is studied and investigated. The fundamental calculation model is discussed. Moreover, the mutual coupling between the array elements is study to understand the steerable performance. Several beam steering techniques are analysed studied. An antenna can be defended as a usually metallic device for radiating or receiving radio waves defines the antenna or aerial as a means for radiating or receiving radio waves. It can introduce and briefly discuss some forms of the various antenna types.

2.2 Monopole Antenna

It is noted that the monopole antenna can be used in many applications like ground based station for wireless communication [8] The monopole antennas have widely used for wireless applications due to its performance such as low vertical polarization and provides an omnidirectional radiation pattern of XZ plane [9]. Figure 2.1(a) illustrates the conventional monopole antenna which performs was half dipole is set perpendicular to the circular ground plane. Figure 2.1(b) shows the basic structure of dipole antenna. the monopole antenna is presented with the physical length of h that can give a current distribution of λ/4 n terms of the feed point current I (0) for $0 \le z' \le h$ [10]:

$$I(Z') = \frac{I(0)}{\sin(kh)} \sin k(h - z') \tag{2.1}$$

The calculation of equation (2.1) occurs due to the accurate ground plane produces a copy pattern with the current distribution of the lower pole. The total pattern that generated from the upper pole and the reflected from the ground plane is propagated from the centre feed line of the dipole the generated pattern at the upper half is proposed an equals gain at all the directions for any angle θ (see Figure 2.1). It can see that the proposed monopole has an electric field of double to the dipole antenna. This is demonstrated a high gain of double to the dipole antenna. Moreover, the directivity of the proposed monopole antenna is also increased to twice higher than the reference dipole antenna. It can summarise that in Table 2.1 the comparison between the monopole antennas that has the different length of 2h above the ground plane. Also, Figure 2.1 shows the different feed points of both the dipole and monopole antennas, which have a length of h/λ. it can be noted that the monopole reactance is changed by changing the radius (a) of the monopole, while the resistance of the antenna independent of conductor radius (a) ($a / \lambda \leq 1$). Figure 2.2 illustrates the radiation pattern of a conventional monopole antenna. The patterns of both monopole and dipole antennas are independent of angle φ and depend only on angle θ. That due to the monopole antenna is symmetric with respect to angle φ in the azimuthal plane (*xy* plane. The following equation is proposed for power density *S(θ)* [10]:

$$S(\theta) = \frac{30 \times W \times P^2(\theta)}{\pi r^2 \times R_a \times \sin^2(kh)} \tag{2.2}$$

where *W* is the radiated power, *r* is the distance to the field point, $k = 2\pi/\lambda$ is the propagation constant, and *P2(θ)* is the pattern factor given by:

$$P^2(\theta) = \left[\frac{\cos(kh\ \cos\theta) - \cos(kh)}{\sin(\theta)} \right]^2 \tag{2.3}$$

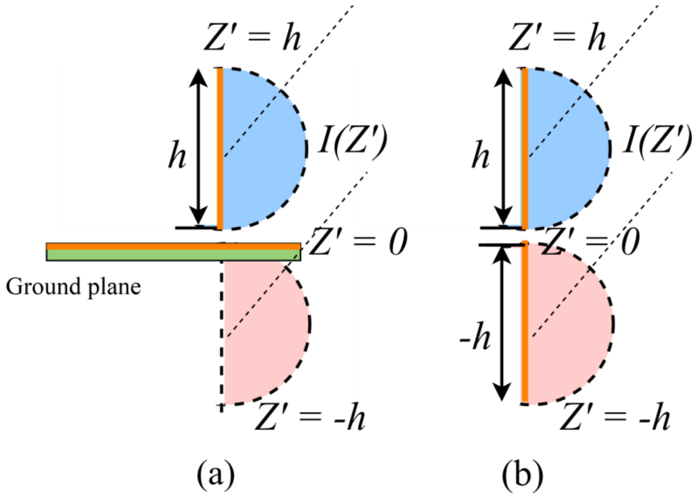

Figure 2.1: (a) Variation of feed-point monopole above ground as a function of height h/λ. (b) the current variations I (z') over the lengths of the monopole and the dipole.

Table 2.1: Relationships between monopole and dipole antennas.

	Monopole Above ground Length=h
Radiation pattern	same as that for dipole
Feed- point reactance (Ra)	R(a)=0.5Ra(2h) dipole
Characteristics (Xa)	X(a)monopole =0.5 X for dipole (2h)
Directivity (Da)	D(a)monopole =2 (Da) for dipole (2h)

To know how the input impedance and radiation pattern of the antenna change as the dimensions of the monopole element and the ground plane very, Figure 2.2 presents a numerical result obtained by *M*. Weiner [11] of the radiation pattern of a quarter-wave monopole element at the centre of a ground plane of radius of zero to infinite wavelength. All polar graphs have the same relative scale.

Table 2.2: Electrical properties of very thin monopole (element length = $\lambda/4$) elements on ground planes of zero, large, and infinite extent [11].

Ground plane Radius (wavenumbers) $2\pi a/\lambda$	Peak Directivity		Directivity on Horizon		Input Impedance	
	$d(\theta)$	$D(\theta)$	$d(\theta=\pi/2)$	$D(\theta=\pi/2)$ (dBi)	Radiation resistance(Ω)	Reactance(Ω)
0	1.543	1.882	1.543	1.882	19.43	$-\infty$
>>> 1, Finite	3.282	5.161	0.820	-0.859	36.54	21.26
∞	3.282	5.161	3.282	5.161	36.54	21.26

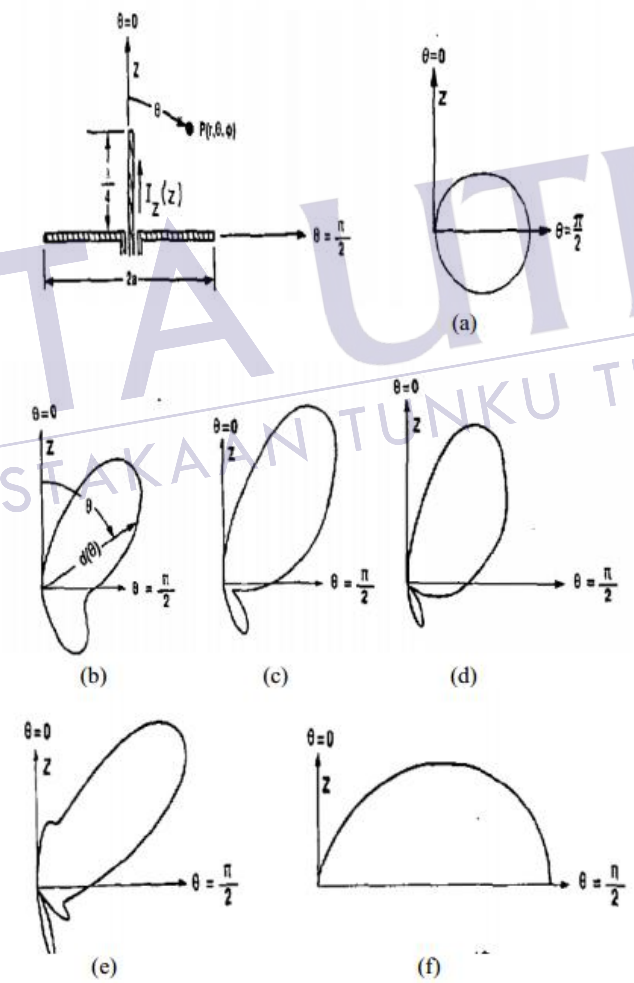

Figure 2.2: Directive gain patterns, for any azimuthal direction, of a thin quarter-wave element mounted on a ground plane of radius 'a'; (a) $2\pi a/\lambda = 0$, (b) $2\pi a/\lambda = 3$, (c) $2\pi a/\lambda = 4$, (d) $2\pi a/\lambda = 5$, (e) $2\pi a/\lambda = \sqrt{42}$, (f) $2\pi a/\lambda = \infty$ [11].

To calculate the input impedance of a monopole antenna, Equation (2.4) which is the radiation resistance of a dipole antenna, for a free-space medium ($\eta = 120\pi$) merely is used [12].

$$R_r = \frac{2P_{rad}}{|I_o|^2} = \frac{\eta}{4\pi} C_{in}(2\pi) = 30 \times (2.435) \cong 73 \qquad (2.4)$$

The dipole has resistance input port gives maximum currant for a dipole of $l = \lambda/2$. The length of the dipole produced the antenna impedance real and imaginary parts. Thus the total input impedance for $l = \lambda/2$ is equal to

$$Z_{in} = 73 + j42.5 \qquad (2.5)$$

From the facts described above, the input impedance of a quarter wavelength monopole above a ground plane is equal to one-half that of an isolated half wavelength dipole. Thus, the input impedance *Zin* is given by

$$Z_{in}(\text{monopole}) = \frac{1}{2} Z_{in}(\text{dipole}) = \frac{1}{2}[73 + \text{j}42.5] = 36.5 + \text{j}21.25 \qquad (2.6)$$

2.3 Mutual Coupling Between Wire Elements

When a wire antenna is placed close to a dielectric body, displacement currents may be induced in the dielectric, if a wire antenna is placed close to a conducting body, conduction currents may be induced to flow in that body. This has the effect of changing the current distribution in the original antenna and so affects its impedance. The currents in the neighbouring body contribute to the total radiation pattern of the antenna, these induced currents are of significant interest [13]. When the size of these adjacent elements approaches a resonant size, then the induced currents are maximized and the effect on the total antenna system may be significant. Such conductors are called parasitic elements, and need not be the same form as the driving elements. Consider the case of two conducting wires lying close to each other and driven with voltages V1 and V2. The currents in the two elements I1 and I2 can be calculated by solving the network equation:

$$\begin{aligned} V_1 &= Z_{11}I_1 + Z_{12}I_2 \\ V_2 &= Z_{21}I_1 + Z_{22}I_2 \end{aligned} \tag{2.7}$$

where $Z_{11}$and Z_{22} are defined as the impedance looking into port 1 and 2 when all other ports in the network are open circuited [11]. In a *p* element array:

$$Z_{nn} = \left.\frac{V_n}{I_n}\right|_{I_m=0,P,m\neq n} \tag{2.8}$$

where $m = 1, 2, \ldots.p$.

$$Z_{mn} = \left.\frac{V_m}{I_n}\right|_{I_m=0,P,m\neq n} \tag{2.9}$$

If the wire elements are resonant at f_0 and have feed points close to the centre of the wire, an open-circuited feed result in two non-resonant wires and little current is induced in the two short wires. For an array of resonant length wires, the calculation of Z_{11} and Z_{22} are simplified by ignoring other impedances of the individual elements in isolation. Similarly, Z_{12} and Z_{21} can be calculated in isolation and so are the mutual impedances between the two isolated elements. These approximations are valid when there is minimal induced current in the array elements with their feed position open circuited. In the case of many such elements, Equation (2.4) can be expanded to include the influence of every element in the array on every other element in the array. This can be written as the impedance matrix equation as follows:

$$\begin{bmatrix} V_1 \\ V_2 \\ . \\ . \\ V_n \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{11} & . & . & Z_{1n} \\ Z_{21} & Z_{22} & . & . & Z_{2n} \\ . & . & . & . & . \\ . & . & . & . & . \\ Z_{n1} & Z_{n2} & . & . & Z_{nn} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ . \\ . \\ I_n \end{bmatrix} \tag{2.10}$$

If all elements have the same length and each is driven at the centre, then $Z_{11} = Z_{22} = Z_{nn} = Z_a$ where Z_a is the input impedance of the dipole in isolation. The far-field radiation pattern E_{TOT} of the array consisting of n elements is given by the sum of the radiation patterns of the elements individually, where the currents are represented by complex numbers, and the phase differences in all directions are taken into account. The radiation pattern E_{TOT} can be written in the form:

$$E_{TOT} = \sum_{m=1}^{n} E(I_m) \tag{2.11}$$

Where $E(Im)$ is the radiation pattern for the nth element carrying current Im. The phase and magnitude of the voltages Vm in Equation (2.4) can be used to control the direction and beamwidth of the antenna array.

$$\begin{aligned} V_1 &\approx Z_{11}I_1 + Z_{12}I_2 \\ 0 &\approx Z_{21}I_1 + Z_{22}I_2 \end{aligned} \tag{2.12}$$

The radiation pattern is still given by Equation (2.8), where n = 2. The calculation of the radiation characteristics of both phased arrays and parasitic antennas requires the solution of the impedance matrix, which includes the self-impedances (the on-diagonal elements in the matrix). The calculation of the mutual impedances is an important part of the derivation of the antenna characteristics.

2.4 Smart Array Antenna

2.4.6 Switched-Beam ESPAR Antennas

The first use of switched parasitic elements in antenna arrays for direction finding was reported in 1971 by Himmel et al. [14]. And Black et al. [15] patented a direction finding array for aircraft navigation using switched parasitic monopole elements on a ground plane formed by the aircraft fuselage. A modification of the Yagi-Uda concept using switched parasitic elements was patented by Gueguen in 1974 [16]. The feed element was a monopole on a ground plane. This was surrounded by some circles of monopoles arranged as a radial array of Yagi-Uda antenna. The array could be directed electronically by changing the impedance state at the feed point of these monopole elements. An alternative approach to using the Yagi-Uda concept in the switched parasitic antenna is to change the effective length of the parasitic elements by switching in reactive elements [17, 18] as shown in Figure 2.3.

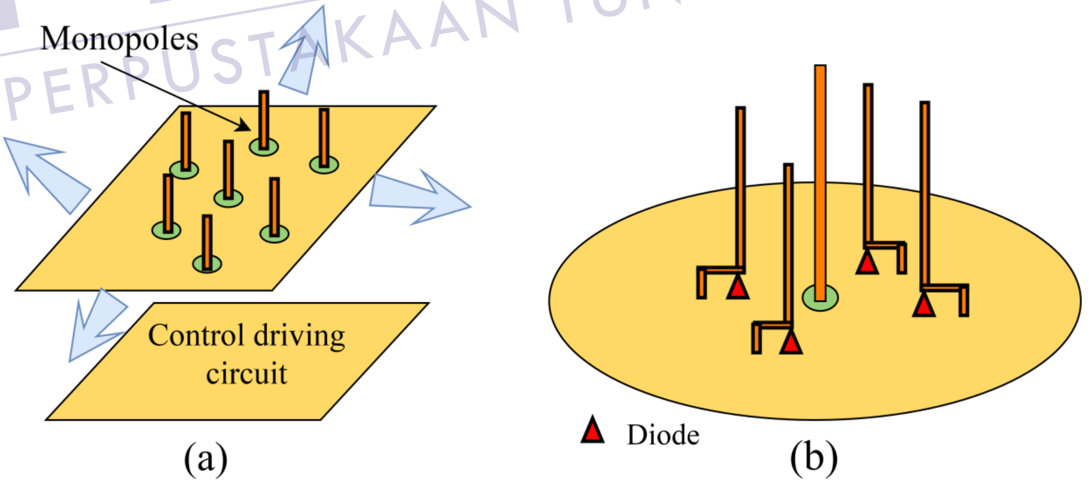

Figure 2.3: (a) Schematic of a circular array antenna architecture for electronic steering, (b) Schematic of a central active element antenna surrounded by parasitic elements with horizontal terminating impedance sections.

In this way, it is possible to change director elements to a reflector element in the array, and so change the direction of radiation. This has the effect of increasing the front-to-back ratio for the antenna in comparison to an antenna in which all elements are of equal length. Two different arrangements of dual-wire antennas, in which there is one driving dipole and one parasitic dipole, are shown in Figure 2.4 [14].

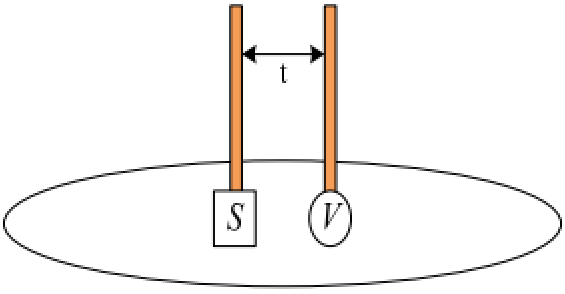

Figure 2.4: Two-wire switched parasitic antennas side-by-side monopoles (*V* represents the driving element; *S* represents the switch in the parasitic elements).

These configurations are the simplest dipole parasitic arrays. The active element is driven by voltage *V*, and the parasitic element is marked *S*. The side-by-side configuration has a practical monopole implementation illustrated in Figure 2.4.The directional characteristics of the array can be controlled by activating the switch at *S*. When the switch is closed, the element is resonant at the same frequency as the driving element if the two elements are of equal length. When the switch is an open circuit, the element will not resonate at that frequency. This is the basis of an electrically controlled smart antenna. A dc electronic signal can control the switch setting and so controls the antenna directional characteristics [13].

In the podcasting, the main radiation pattern is beamforming into the mobile node by using switched beam system. The beam selection is updated by comparing the received signals power then switching the main lobe direction. Increasing the signal strength and reducing interferences at 6dB of 88% suppression improves performance of the system by using this antenna design, that are not in the same direction as the signal [19]. Conversely, the interference will not be suppressed when interference is within the same lobe as the signal. This is a significant disadvantage of the switched beam approach. 8 antennas circular loop array antennas are presented (shown in Figure 2.5) that can cover a 360^{o} field of view. The antenna system diameter is 3mm and the length is 10 mm. At 5.8 GHz the minimum width of the beam steer is realised lower than 40. This design has been adaptive to the beam by using both adaptive array and switched beam. The proposed design is able to track the user by using smart adaptive and keep in direct connection with the users with avoiding the interference. This antenna design realized a higher throughput and long coverage range due to its high gain.

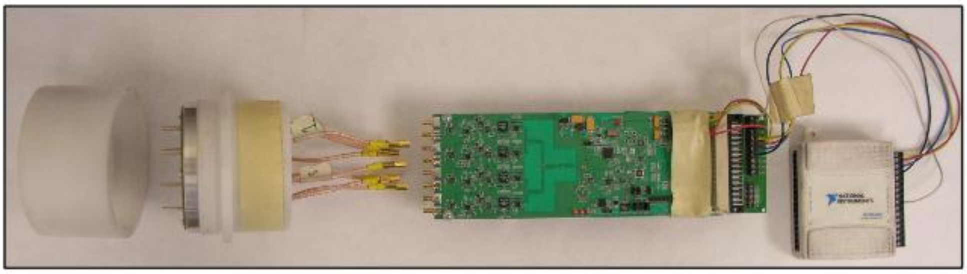

Figure 2.5: Smart antenna system [19].

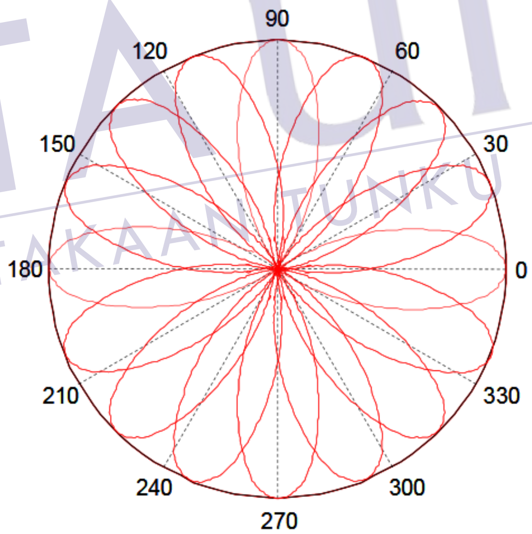

Figure 2.6: Switched beam antenna with fixed radiation pattern [19].

A reconfigurable pattern antenna is introduced in [20]. This design is operated with multi-state (eight cases), which is able to achieve a steerable beam on to eight specific directions as shown in Figure 2.7. The proposed eight reconfigurable beam cases are able to cover and track the users into all the directions with H-plan horizontal pattern. Controlling the eight switches into modes of (ON, or OFF) gives the required beam steer direction that has a number from K1 to K8. For every

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